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ABSTRACT

A revised version of a paper presented at a mini-plenary session of the 88th Annual Conference of the American Society for Engineering Education, University of Massachusetts, Amherst, June 25, 1980, is discussed. A panel of industry and government representatives addressed the question of the kinds of educational backgrounds that will be called upon in the 21st century by the users of engineering graduates and discussed the impact of advancing technology as well as the increased interface between society and technology in various segments of the user world. (Author/SK)

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ENGINEERING EDUCATION FOR THE 21ST CENTURY

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June 1980

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PREFACE

This paper was presented at a mini-plenary session of the 88th Annual Conference of the American Society for Engineering Education, University of Massachusetts, Amherst, June 25, 1980. The mini-plenary session was titled "Industry's View of Engineering in the 21st Century" and the conference program gave the following as its charter:

> A panel of industry and government representatives will address the question of the kinds of educational backgrounds that will be called upon in the 21st century by the users of engineering graduates. The panel will discuss the impact of advancing technology as well as the increased interface between society and technology in various segments of the user world.

The present version of the paper differs slightly from the one presented orally at the conference: A few editorial revisions have been made, a few points have been embellished, and a few asides have been deleted.

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ENGINEERING EDUCATION FOR THE 21ST CENTURY

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1. INTRODUCTION

Each speaker in this session addresses our topic from a different perspective, for each represents a different user group. I represent the policy analysis user group. If instead I represented aerospace engineering or heavy construction, you'd doubtless already know a lot about my user group. But since policy analysis is relatively esoteric, and has had the unfortunate habit of changing its name whenever its horizons broaden, I think I should spend a little time describing what policy analysis is. That will be Chapter 2 of my talk.

Chapter 3 is called "Some Ruminations on What the Growing Interface Between Technology and Society Implies for Engineering Education."

Chapter 4 is called "Some Speculations About Future Trends and What They Imply for Engineering Education."

Chapter 5, which will be bold and brief, is entitled "Conclusion."

2. WHAT IS POLICY ANALYSIS

Policy analysis is a systematic approach to making complex choices, usually in the public sector. It has been successfully applied in the attempt to choose the preferred course of action in such dissimilar problems as cleaning up air pollution in major cites; improving educational and medical services to mentally and physically handicapped children; deploying and dispatching fire department and other emergency services; modifying automobile designs to save gasoline; and managing the water resources of an entire nation.

Policy analysis is an inquiry whose purpose is to assist decisionmakers in choosing a preferred course of action from among complex alternatives under uncertain conditions.

The word "assist" is intended to emphasize that policy analysis is not meant to replace the judgment of the public policy decisionmakers (any more than an X ray or a blood test is meant to replace the judgment of medical doctors). Rather, the goal is to provide a better basis for the exercise of that judgment by helping to clarify the problem, outline the alternatives, and compare their consequences.

The word "uncertain" is meant to emphasize that the choices must generally be made on the basis of incomplete knowledge, about alternatives that do not yet physically exist, and whose predicted consequences will occur--if at all--only in an unknown future.

Policy analysis is performed in government, at all levels; in independent policy research institutions, both for-profit and not-for-profit; and in various consulting firms.

With this background, I can now turn to my main topic: From the perspective of the policy analysis user group, what should engineering education for the 21st century be like?

3. SOME RUMINATIONS ON WHAT THE GROWING INTERFACE BETWEEN TECHNOLOGY AND SOCIETY IMPLIES FOR ENGINEERING EDUCATION

Before I begin my ruminations, I must tell you they assume that the general approach to policy analysis in the 21st century will not be much different from today's approach, although specific tools may change. I feel fairly confident about this assumption because I believe policy analysis is primarily an art rather than a science. I might draw an analogy with architecture. If Frank Lloyd Wright were alive today, I think the intellectual process by which he went about designing buildings would probably be very similar to the one he used throughout his career, although the buildings would turn out quite differently because he had different materials and construction techniques available.

Making this assumption, I shall identify desirable characteristics for all policy analysts, including engineers, and then indicate some additional characteristics that I think are important for engineers working in policy analysis.

DESIRABLE CHARACTERISTICS FOR ALL POLICY ANALYSTS

Usually, the policy analysis of a broad problem makes use of an interdisciplinary team. This is not merely because a broad study is complex. Rather, a more important reason is that the questions the study raises will look different to an economist, a mathematician, a lawyer, a political scientist, an engineer, or a biologist--and different ways of looking at a problem are extremely helpful in finding a solution. The following characteristics appear desirable for all policy analysts, regardless of their educational discipline:

- To facilitate communication and promote synergy, each policy analyst should know several disparate fields. This allows a policy analysis team to bring many disciplines to bear on a problem in a manageable size group. In effect, what I am arguing for is something that I once heard called the "T man." If you imagine plotting the depth of a person's knowledge about different fields on the Y axis, and the number of fields about which the person has knowledge on the X axis, the kind of person I am talking about looks like an inverted T: He has deep knowledge in several fields and broad knowledge spanning many fields.

- The policy analyst should be a facile and fluent user of the computer.

- The policy analyst should be good at building mathematical models, for these are often needed to predict the potential effects of new systems. But besides skill in the art of modeling, this will require understanding the processes to be modeled:

  - physical
  - ecological/environmental
  - social

  I think this portends the need for broader, rather than deeper, education.

- The policy analyst should be a pragmatic problem-solver rather than a theoretician who wants to maintain the purity of his discipline. (The latter gave the Ivory Tower its bad name.) The approach should be tailored to fit the problem, rather than the problem being simplified to fit a standard approach.

- The policy analyst must be an effective communicator in both speaking and writing: A grade "A" explanation of a grade "B" analysis will do more to change public policy than a grade "A" analysis with a grade "B" explanation.

- The policy analyst should understand how bureaucracy works, and in fact, how to make it work.

- Finally, the policy analyst must have great self-reliance and high tolerance for amorphousness and ambiguity.

ADDITIONAL CHARACTERISTICS DESIRABLE FOR POLICY ANALYST ENGINEERS

In addition to the above characteristics, the policy analyst engineer needs:

- To be a "general" engineer rather than a specialist; he will often need to act as an interface between the policy analysis team and the "current" experts in relevant fields. I say "current" because I think both the fields and the experts will change rapidly in the 21st century.

- To take a "systems view" of problems.

- To have considerable breadth in

  - mathematics, particularly in operations research, which is useful in modeling;
  - decision analysis, which offers tools for dealing explicitly with uncertainty;

- probability and statistics--because much of the world of the 21st century will still be stochastic;
- accounting--because money (which has been called "the mother's milk of politics") and budgets are crucial factors in public policy decisions;
- engineering economics--because you ought to be able to figure the costs of things you are going to build;
- regular economics--because the marketplace will probably continue to play a central role in society;
- some ecology/biology--because we are all residents of spaceship Earth and we need to learn how to preserve a proper balance among the many species if ours is to survive and thrive;
- in liberal arts, because it is important to understand civilization so that you can improve it rather than merely maintain it.

4. SOME SPECULATIONS ABOUT FUTURE TRENDS AND WHAT THEY IMPLY FOR ENGINEERING EDUCATION

It's impossible to forecast the future in detail. There are either virtually or actually an infinite number of possible futures. But, having said that, I'll venture some speculations about general trends--they're trends I consider "good bets," although far from "sure things."

Besides being more complex, I think the world of the 21st century will be extraordinarily different from the world of today--so different that, no matter how fanciful our speculations, they will greatly underestimate the reality. We tend to think and forecast in terms of evolutionary changes. But revolutionary changes--some technological, some social--seem certain in the next 20+ years. And this greatly complicates both the process and the planning of education.

Several trends appear to presage major changes in our world and hence in needs for engineering education. I'll discuss the trends and what I think they imply for the engineer's educational needs. How one pedagogically meets these needs, I'll mention only briefly; as they are fond of saying in the textbooks, "the details are left as an exercise for the student"--in this case, you, the audience.

TREND 1: THE COMPUTER REVOLUTION

I think that the ongoing computer revolution will have an impact approaching that of the Industrial Revolution--but more quickly and more abruptly. Recall that the computer has brought enormous changes and evolved through three generations in the last 20 years. It seems inevitable that the computer will bring even more enormous changes in the next 20 years. Let me mention four examples relevant to engineering education.

First, the acquisition and retention of factual knowlege by humans will be less important in the 21st century than today. Computers will be able to retrieve information, answer complex questions, recognize patterns, draw inferences--and learn (major developments in artificial intelligence appear in prospect). This mea less emphasis on students learning factual material.

Second, process control computers and robots will be able to perform actual physical experiments whose component operations (or maybe just goals) have been specified by engineers: This implies less engineering education emphasis on learning certain experimental skills and techniques; e.g., instrumentation setup, instrumentation engineering, materials testing.

Third, mathematical models will be much easier to build and use. And it will be easy and natural to tap into large data bases of almost any conceivable kind. (There may even be various kinds of "information utilities.") This implies that mathematical models will be used to simulate processes under study more often, further reducing the need for physical experiments and models; wind-tunnels are an example of a potential casualty.

Fourth, increasingly, problem-solving and research will be undertaken by man/machine symbiosis--man and computer in partnership; the division of labor between man and machine will reflect their relative advantages and skills. Many traditional scientific and engineering tasks will be done by the computer when the man merely provides the data or roughly describes the problem. For example, computerized plotting of data--even in three dimensions--is already a reality. And computers will be able to produce any kind of engineering drawings desired without an engineer or draftsman putting pencil to paper. (Of course, the drawings will probably be unnecessary because the computer can pass the information content of the drawing to a process control computer that will handle the manufacturing.) And many skills laboriously learned today will be unnecessary for the computer-assisted engineer of the 21st century: When computers can recognize and manipulate symbols (soon), then it will be unnecessary for man to know the various integral forms or the techniques of integration such as substitution or integration by parts. (This is analogous to how the advent of hand-held calculators rendered obsolete those traditional engineering tools, the slide rule and the table of logarithms.) Of course, it may be that computers will just do the integration numerically in the blink of an eye whenever you write down an integral sign; there are systems approaching this now.

All this suggests that the scientist or engineer of the future must, perforce, emphasize his creative and artistic gifts. And "artistic" conveys the proper flavor, I think: Man's taste and imagination--and his capacity to set and pursue "humane" goals--may constitute his principal advantage over the machine for various scientific and engineering endeavors. What changes in engineering education will help?

1. Concentrate more of the curriculum on synthesis, including design, rather than analysis; i.e., the "art" rather than the "science" of engineering.

2. Teach problem-solving more formally, particularly for unstructured problems. Engineering clinics, like the one at Harvey Mudd College, can help. So can the use of case studies. The first speaker, Dr. Vollmer, mentioned how business school graduates are easing into engineering project management positions. Many business schools successfully use the case study approach, and maybe we can profit from their example.

3. Try to improve creativity. Some suggestions as to how:

   - Try to develop "horizontal thinking" rather than "vertical thinking." Edward de Bono, who has written a number of insightful books on creativity, has found that horizontal thinking is very important to creative problem-solving. The distinction between horizontal and vertical thinking basically is this: Suppose you are trying to find oil in a broad area that geologists think is promising. If you are a vertical thinker, when your well reaches five thousand feet and hasn't struck oil, then you drill another five thousand; and, if you still have not struck oil, you drill yet another five thousand; etc. If you are a horizontal thinker, however, you drill down five thousand feet (say) and, if you haven't struck oil, then you move over to a different site in the potential oil field and sink another shallow well; if you don't strike oil there, you try yet another location, etc. Incidentally, De Bono has written a marvelous book that, for me at least, pretty much proves that children are born quite creative, but we systematically stamp it out of them in the primary and secondary schools. The book is called The Dog Exercising Machine. To test children's creativity, De Bono wanted a problem that had no existing solution, could be described to children between the ages of 3 and 14, and that would have a technological solution. So he asked children to describe for him their designs for an automatic machine to walk dogs. The book contains sketches of the childrens' designs, their description about how the designs were supposed to work, and De Bono's comments about the approaches to creative problem-solving the children employ. (See also De Bono's The Mechanism of Mind, The Five-Day Course in Thinking, and PO: A Device for Successful Thinking. Another excellent book on creativity from an even broader perspective is Ref. 1.)

   - Exploit the latest theory and knowledge about the differing functions of the two hemispheres of the brain. Use "exercises" to develop the right-hemisphere (the artistic side). (See, for example, Refs. 2 and 3.) My personal theory is that mankind's most creative geniuses (such as Da Vinci and Einstein), unlike the vast majority of people, were extremely well developed in both hemispheres of the brain, and had strong cross-connections between the hemispheres.

TREND 2: THE LEISURE REVOLUTION

The amount of leisure time each individual has will probably increase as technology advances and as other social value systems displace the "work ethic." One task of engineering education should be to help prepare the individual for this so that he avoids the anomie and disorientation that leisure is bringing to some of our contemporaries. This may imply engineering education should put more emphasis on the exposure of students to things that might become hobbies, like art and music, in addition to things useful in his career or the belles lettres that make a well-rounded man.

TREND 3: THE SUBSTITUTION OF COMMUNICATION FOR TRANSPORTATION

I think that communication will increasingly substitute for transportation. In future schools, a student may remotely "tune in" on a class rather than physically attending it; this may have serious implications for the physical plant of colleges, the enrollment it can handle, etc. (Administrators beware!) In future society, the same trend might have large and far-reaching implications. It might improve some social problems; for example, a reduction in travel would reduce associated pollution and energy consumption. But it might create strange new problems. For example, in the book The Naked Sun, Isaac Asimov describes a society where all people live alone and communicate with each other almost exclusively by TV screens. And in that society there is a distinction between "viewing" and "seeing." "Viewing," which is the normal mode of human interaction in this society, occurs when you communicate with another person through your TV screen. "Seeing," which occurs when you actually meet face to face, is considered very distasteful in this society and generally occurs only when necessary for procreation.

* * *

I'm going to argue that this substitution of communication for transportation trend, in combination with the computer revolution and the leisure revolution trends, has two major implications for engineering education:

1. It should teach people how to learn on their own, taking advantage of whatever learning aids future technology may afford. In the recent past it was said people would need to re-earn their Ph.D. after seven years; with the exponential growth of knowledge, the number of years is likely to drop by the 21st century.

2. It should expand students' background in the liberal arts. This will help them do socially conscious engineering design, as well as enrich their lives by helping them understand and appreciate civilization. Incidentally, what I am urging here is not additional courses of the predigested, unappetizing "social science for engineers" variety.

TREND 4: THE TECHNOLOGY-INTENSIVE SOCIETY

It seems almost certain that the world of the 21st century will be more complex and more technologically based than the world of today. But the more society relies upon technology, the more vulnerable it becomes to system failures such as blackouts or nuclear plant accidents and to adverse side effects such as pollution, computer crime and privacy abuse, carcinogenic chemicals, traffic accidents and traffic congestion, and so forth. To reduce such vulnerabilities, public policymakers need to become more skillful at evaluating new technology and its implications, as well as the analyses and expert judgments about them, which often disagree. This suggests the need for greater participation by engineers and scientists in policymaking--as policymakers instead of merely as occasional advisors or ordinary citizens. (How many engineers and scientists are congressmen, state officials, city council members, etc.?) Government of a complex, technological society is too important to be left to the lawyers (as Clemenceau might have said were he alive today). I don't know precisely how engineering education can best prepare or encourage future engineers to become more politically involved, but I believe it is important.

OTHER TRENDS

There are lots of other trends. I'll just mention their names and not talk about them at all.

- Decreasing natural resources and the increasing pollution on "spaceship earth"
- Genetic engineering
- The implications of possible climate changes
- Population growth
- "Space, the last frontier" (as the prologue to the TV show STAR TREK refers to it)

5. CONCLUSION

The fundamental purpose and task of education is not to teach people how to be, to be like their teachers in a world like their teachers' world. Rather, it is to teach them how to become, become whatever they want in whatever kind of future world they live. To successfully face the world of the 21st century, which will be not only extraordinarily different from our own world, but also from most of our speculations, I believe engineers will need a much broader range of knowledge and a much greater degree of adaptability.

In effect, I am explicitly proposing that engineering education be based on--and designed to produce engineers who embody--the theory of adaptive control. This means extending the engineering curriculum to embrace many fields outside the traditional purview of engineering, and developing institutional mechanisms to ensure that the curriculum keeps evolving dynamically to anticipate the needs of the future rather than statically preserving the pedagogic traditions of the past. Such changes will pose a tremendous challenge for engineering educators, for despite their more traditional training, they must adapt before future students can. And, unless engineering educators can meet this challenge, it could become "the Catch 22" of 21st century engineering education.

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